**DETERMINING THE PRE-POSITIONING PROBLEM OF DISASTER RELIEF WAREHOUSES IN ASIA-PACIFIC REGION**

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# Introduction

## Background

Natural disasters frequently, such as earthquakes, floods, drought or man-made crises (civil unrest, war, political/tribal disturbance) happen in various areas around the world that seriously disrupt daily lives of people and also cause death (Roh et al., 2015). Natural disasters can occur with little or no warning and there is strong evidence that globally, natural disasters have increased in terms of both frequency and impact. Disaster-prone areas are experiencing more frequent emergencies and previously benign areas, unaffected by extremes, are now affected. Averagely, the total number of natural disasters occurring annually is around 500 times. The number of people affected by natural disasters are around 140,000 and over 500 disasters are reported death. (CREDEM-DAT, 2018). From 2011 to 2017, around 215 to 265 reported disasters occurred in Asia, the frequency was much higher than other continents. In addition, the total number of reported death toll of disasters in Asia is also at the highest level by continents (Figure 1).

Source: CREDEM-DAT, 2018

Figure 1: Total number of reported disasters, by continent

Many studies have addressed the importance of the preparedness phase and the need for pre-positioned warehouses in humanitarian relief logistics, but only a small number of papers are related to the location decision (Balcik and Beamon, 2008). Gatignon et al. (2010) illustrate the implementation of a decentralised model at the International Federation of the Red Cross (IFRC) using the pre-positioned warehouse concept. Campbell and Jones (2011) use a cost model to examine the preposition of supplies and the volume of goods in preparation for a disaster. Different regions are subject to different disaster types and while the occurrence of disasters is irregular on an annual basis, there is a trend for large scale disasters to occur in certain areas. Nonetheless, the most common major natural disasters that affect specific regions are floods, wind storms, droughts and earthquakes, giving some predictability which can assist in the preparedness phase, but timing, extent and duration of such emergencies remain unpredictable. As the characteristics of disasters around the world vary from region to region it is likely that different combinations of aid stocks could be pre-positioned in different locations. This is in part already serviced through shared facilities provided by for example the United Nations (UN) (Heaslip, 2013). In this case, how to construct an appropriate model to different region has become a major task for the recent research.

When emergencies occur, the most important thing is to supply food, drugs, or other necessities to the victims throughout the entire disaster and post-disaster without disruption. From previous researches revealed that some people died for lacking of these necessities rather than dying for a disaster. Thus, the main task of saving lives from a natural disaster is storing the relief materials in advance and distributing them effectively, which explained why the pre-positioning is significant for a rapid disaster preparedness and response.

The United Nations Humanitarian Response Depot (UNHRD) was established with the idea of pre-positioning emergency relief items for a quick response at the onset of any disaster. First UNHRD warehouse was established in the year 2000 at Brindsi, Italy. Until now, UNHRD is a network of six strategically located depots that procures, stores, and transports emergency supplies on behalf of the humanitarian community. With shift in strategic focus of relief organizations towards pre-positioning and UNHRDs attempt to expand its network, urgent need was realized to determine the pre-positioning problem of disaster relief warehouse. Comparing with great number of natural disasters and the enormous damage cost, only two depots of UNHRD (UAE & Malaysia) is obviously inadequate. There is no doubt, capacity building measuring is needed in this region which can enable to deal with aftermath of natural disaster effectively. In this case, how to identify an effective way to select the optimal location for a disaster relief warehouse in Asia-Pacific is the main purpose of this research. There are five sections in this paper. Following this introduction is a review of previous literature on humanitarian logistics and pre-positioning. The methods which are applied to undertake location choice are also reviewed in this section. Section 3 discusses the research methodology, including data analysis methods. Data construction and the results of the calculation using the developed computer calculator are presented in section 4. The discussion and conclusion drawn from the research findings and their implications for port policy-makers are discussed in the final section.

# Literature Review

## Pre-positioning problems

Pre-positioning problems is one of the most important research topics in humanitarian logistics. Kovács and Spens (2009) emphasized the importance of the location and regional presence of a humanitarian organization in disaster relief. The location and local capacity building of pre-positioning of relief items is significant in improving the performance of a humanitarian supply chain. However, there are limited researches which focus on the pre-positioning problem of disaster relief warehouses. Yong (2006) tried to select the optimal location for a plant under the main objective of minimizing the total cost and maximizing the use of resources. Chen (2001) determined a new multiple criteria group decision-making method to solve the distribution centre location selection problem. Ashrafzadeh et al. (2012) successfully apply the TOPSIS to a real warehouse location decision problem of a company in Iran. Most of these location-selection researches are target in obtaining commercial benefits. In the research, the authors provide an overview on various criteria used. And the typical criteria on the previous studies are: cost, value and benefits, environmental risks, resource accessibility and utilization, public facility accessibility, political matters and regulations, competition, economical, population, capacity, distance, and suitability.

From previous literatures, we can recognise that cost is the most important criteria in selecting an optimal location for business facility, considering the main objective of maximize the profit. However, because of the different objectives between traditional distribution systems and relief distribution systems, different criteria should be considered in location-selecting. Roh et al. (2013) suggested five critical factors considered for locating humanitarian relief warehouses. In particular, they utilized Analytical Hierarchy Process to determine the important weights of evaluation criteria. The mainly results are presented in Table 1. It shows that cooperation from the local government is the most critical factor and follows by national stability and cost. In conclusion, in spite of political factors, there are three factors influence the choice of configuration for a disaster relief pre-positioning network: 1. Up-front investment (initial inventory stocking and warehouse setup); 2. Operating costs (relief-item purchasing, transportation, and warehousing cost); 3. Average response time.

|  |  |  |  |
| --- | --- | --- | --- |
| Rank | Criteria | Normalized Weight | Accumulated Weight |
| 1 | Cooperation | 0.2908 | 0.2908 |
| 2 | National stability | 0.2282 | 0.5190 |
| 3 | Cost | 0.2270 | 0.7460 |
| 4 | Logistics | 0.1525 | 0.8985 |
| 5 | Location | 0.1015 | 1.0000 |
| Total Weight | 1.0000 |

Source: Roh et al., 2013

Table 1: Critical factors for locating humanitarian relief warehouses

Another assumption which is applied in this study that the initial capital is ample and highlight the importance of average response time in location selection. This assumption is from Duran et al. (2011). The authors stated that if the initial investment is ample, the warehouse operating cost will not be very significant because of government subsidies and collaboration with the UNHRD and other humanitarian organizations. Balcik and Beamon (2008) developed a maximal-covering model to determine the number and the location of disaster relief warehouse. The inventory of supplies is also considered in their study. In this case, a mixed-integer liner program is used to solve this pre-positioning problem in this study. The gap of the previous studies is obvious that limited researches have applied a study on pre-positioning problem of disaster relief warehouse, especially in Asia-Pacific region. The possible contributions from this study can be listed as follow: 1. This study emphasizes the significance of response time on the pre-positioning problem of a disaster relief warehouse. 2. Asia-Pacific region is the key geographical region which this study focused on. 3. The newest disaster data from 1969 to 2017 is used in this study. And the research question from this study should be: Where is the optimal location for pre-positioning humanitarian aid materials in Asia-Pacific region to minimize delivery lead-time to those people who will need it.

# Methodology

# Data

This research attempts to determine the optimal location of pre-positioning warehouses for the shortest response time in Asia-Pacific region. The reported disaster data from 1969 to 2017 in Asia-Pacific are considered as the predicted demand. In total, 2707 events that resulted in at least 10 deaths between the years of 1969 and 2017 in Asia-Pacific. Grid lines were projected onto the earth’s surface. When a disaster data located in that grid cell, the central of that grid cell will be assumed to represent

Figure 2: Potential disaster (demand) locations

the location of the demand. The grid cell dimensions were selected as 10 degrees (10◦) of latitude and 10 degrees (10◦) of longitude. If a grid cell contained a disaster that caused at least 10 deaths between the years of 1969 and 2017, the demand for that disaster will be located in that grid cell. Figure 2 illustrates the locations of potential disaster demand. The red numbers stand for the number of the disasters which the grid cell contains and the black numbers stand for the total death toll in that grid cell during 1969 to 2017.

## Key assumptions of the Model

To determine the optimal location of pre-positioning warehouses in Asia-Pacific region, a mixed-integer programming (MIP) location model is applied in this research. This approach can be applied successfully to solve certain practical site location problems (Elson, 1972). Many researches also used this model to solve the facility location problem in different fields (Balcik and Beamon, 2008; Amrani, et al. 2011; Samuelsson, 2016). The model considers a set of demand instances and finds the optimal location of relief warehouse that minimizes the average response time over the demand instances.

## Demand model

In most facility location and network flow optimization problems, demand is treated directly. For humanitarian supplies, demand would be measured in terms of the number of water-purification systems, the number of electrical generators, or the number of tents. To complicate matters further, operations often bring too many, or less, of any given non-consumable due to uncertainties on the ground. In other words, there is no clear direct signal of demand. Therefore, this study aims to approximate demand indirectly. The size of the operation is, in turn, proportional to the number of people being offered relief. From the data available, the best estimation for this demand is the number of displaced people, or the number of homeless. Therefore, the assumption is that the number of affected population by a hazard is proportional to the non-consumable material requirement. Therefore, the assumption is that the number of affected populations by a hazard is proportional to the non-consumable material requirement. The number of homeless is summated for each demand point over time and it is taken as an average per annum. This variable is "mean annual homeless" and is measured for every demand point being considered in the model. The variable is represented as:

$H\_{j}$= mean forecasted annual homeless for demand point j

For this research, the only measure of central tendency used is the mean. Standard deviation is not relevant to location decisions.

## Distance model

Pre-positioning implies that stocks are already stored in the facility, the path from vendor to facility is not time-sensitive and non-critical. For the sake of simplicity in the optimization model, and due in part to the data available for humanitarian relief activities, this delivery chain has been simplified yet again: considering only the path from source to destination. This assumes that transaction times are constant, regardless of facility location. Therefore, the model considers only the point-to-point arc from disaster relief warehouse to demand point. The variable is represented as:

$d\_{ij}$= geographical distance from warehouse i to demand point j

The distance from a candidate disaster relief warehouse to a demand point is calculated using Haversine method. The Haversine theorem is used to calculate the lengths of two points on the surface of the earth based on longitude ($φ$) and latitude (λ) (Hartanto et al., 2017). It is a method of knowing the distance between two points by taking into account that the earth is not a plane but is a plane of a degree of curvature.

This algorithm is applied to establish a direct distance between points that can be stretched in a triangular form where a, b, and c are the distances to be calculated. In this case, between ($φ\_{i}, λ\_{i}$) and ($φ\_{j},λ\_{j}$), the Haversine method assumes that the earth is spherical and uses the formula:

r = Earth's equatorial radius = 6378137 m

$∆φ=φ\_{j}-φ\_{i}$

$∆λ=λ\_{j}-λ\_{i}$

$a=\left(sin^{2}\left(\frac{∆φ}{2}\right)+\cos(\left(φ\_{i}\right))\right)\*\left(\cos(\left(φ\_{j}\right))\right)\*(sin^{2}(\frac{∆λ}{2}))$

$c=2\*atan2(\sqrt{a},\sqrt{\left(1-a\right)})$

$d\_{ij}=r\*c$

The actual network of airports, roads and river ways is de-emphasized, the model is under the assumption that all the demand points can be approached by air.

## Formulation

A service level is the ability that the warehouse can satisfied the demand in a quick response. Therefore, the objective function for the formulations aimed at determining the sensitivity of distance to warehouse proliferation is the minimization of average distance to forecasted homeless people. From this point forward, be referred to as simply distance per capita. This implies the sum of all the arcs from the disaster warehouse to all the people forecasted to be homeless is minimized. The formulation uses the product ($d\_{ij}\*H\_{j}$) as the formula for the sum of all arcs from a facility to all the people forecasted to be at risk at a given demand point.$ d\_{ij}$ is the geographical distance from warehouse i to demand point j. $H\_{j}$ is the annual mean homeless, or in other words, the forecasted number of displaced people at demand point j. That the product of the two variables multiplies the distance by the number of people indicates the sum of all the arcs from that facility to every person at that location. Distance per capita is thus expressed as$\frac{\sum\_{ij}^{}d\_{ij}H\_{j}W\_{ij}}{\sum\_{}^{}H\_{j}} $, where $W\_{ij}$ is the decision variable (with a value of 0 or 1) of the optimization because it determines if an arc (actually, the sum of all the arcs from a facility at point i to all the forecasted homeless people at point j) is 'active'. The formulation simply aims to identify optimal positions of n candidate warehouse locations so that distance per forecasted homeless person is minimized. And it is as follows:

$min\frac{\sum\_{ij}^{}d\_{ij}H\_{j}W\_{ij}}{\sum\_{}^{}H\_{j}} ∀i,j$

Index Sets

*I*  set of possible pre-positioning warehouses

*J*  set of regional demand locations

Variables

$W\_{ij}=\left\{\begin{array}{c}\&1, if the warehouse i is assigned to demand point j \\\&0, otherwise\end{array}\right.$

Parameters

$d\_{ij}$ geographical distance from warehouse i to demand point j.

$H\_{j}$ mean of annual homeless affected by natural disasters in demand point j.

Three data sets need to be collected for the two variables of the optimization problems:

1. The mean annual homeless for every demand point (for $H\_{j}$ value).

2. Latitude and longitude coordinates for all demand points$((φ\_{j}, λ\_{j}$) values used to calculate $d\_{ij}$).

3. Latitude and longitude coordinates for all candidate warehouses.$ ((φ\_{i}, λ\_{i}$) values used to calculate $d\_{ij}$).

## Candidate warehouse locations

Currently, there are two depots under UNHRD which are located in Asia (UAE and Malaysia). Both of them mainly cover west and south Asia. In this situation, the candidate locations in this research will be selected from East Asia. Due to the stability of a country has a significant influence on the sustained and effective relief supply chain, it is important to exclude the candidate warehouses from a country which hit by a civil or unrest. Thus, the geographical factor is the main factor that the author considered when choosing the candidate sites for disaster relief warehouse. The sample cities should facilitate with both good airport and seaport and low historical disaster occurrence probability (to minimize the possibility of losing a warehouse to a disaster itself). 13 potential sites are selected in this research, nine of them in China (Tianjin, Dalian, Qingdao, Shanghai, Ningbo, Xiamen, Guangzhou, Shenzhen, and Hong Kong), two of them in Japan (Tokyo and Osaka), one in Korea (Busan), and one in Taiwan (Kaohsiung).

# Analysis and result

In the research, we used 2707 demand instances from the last 60 years worldwide, in which the warehouse was needed to respond to a disaster or a group of disasters without any replenishment. The objective function of the MIP model minimizes the average of the weighted response times over the 43 demand points. And when we ensure the demand points, the affected population of each point is ensured too. In this context, $\sum\_{}^{}H\_{j}$ is a constant value, so the formulation can be simplified as below:

$min\sum\_{ij}^{}d\_{ij}H\_{j}W\_{ij}$

Let $SL\_{i}$(service level of candidate location i) =$\sum\_{j}^{}d\_{ij}H\_{j}$

$SL\_{1}=d\_{11}H\_{1}+d\_{12}H\_{2}+d\_{13}H\_{3}+d\_{14}H\_{4}+\cdots +d\_{143}H\_{43}$

$SL\_{2}=d\_{21}H\_{1}+d\_{22}H\_{2}+d\_{23}H\_{3}+d\_{24}H\_{4}+\cdots +d\_{243}H\_{43}$

……

$SL\_{13}=d\_{131}H\_{1}+d\_{132}H\_{2}+d\_{133}H\_{3}+d\_{134}H\_{4}+\cdots +d\_{1343}H\_{43}$

According to this result, among 13 possible locations, the smallest SL value is SL (29.82, 121.47) which is Ningbo city. The result shows that Ningbo city has the minimal total distance to all affected persons. And as a result of constant $\sum\_{}^{}H\_{j}$ value that Ningbo city also has the minimal weighted distance to an affected person comparing other candidate locations. In order to simplify the calculation, we assume that the average maximum speed of various cargo aircrafts, is approximated to be 500 km/hr. And the transportation time is assumed to be only air transport with no consideration of refuelling stops. In order to figure out whether Ningbo has any comparative advantage in a quick response to a disaster comparing Dubai and Subang, the same method is used to collect the transportation time from Dubai and Subang to each demand point. In Table 2, the descriptive analysis of transportation time for these three locations are presented. It is obviously that Ningbo has the least average transportation time comparing with Dubai and Subang. The minimum value 0.04 (Dubai) and 0.88 (Subang) illustrates that these two warehouses are close to at least one disaster demand point. Accordingly, Ningbo is possible to have less disaster occurrence probability than Dubai and Subang. It is more unlikely for Ningbo losing a warehouse to a disaster itself. The service rates of Figure 2 illustrated that how much affected persons can be reached within certain transportation time. All the 43 demand points in Asia can be reached within 19 hours from either warehouse location. In particular, Ningbo can reach 40% of the affected persons within two hours and almost 80% within seven hours. In summary, Ningbo is the optimal location of a disaster relief warehouse in Asia-Pacific region from a geographical view out of 13 candidate locations.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   | N | Range | Minimum | Maximum | total | mean | S.D. |
| DUBAI | 43 | 18.45 | 0.04 | 18.49 | 385.06 | 8.95 | 4.83 |
| SUBANG | 43 | 16.30 | 0.88 | 17.18 | 349.98 | 8.14 | 4.13 |
| NINGBO | 43 | 16.12 | 1.28 | 17.40 | 337.73 | 7.85 | 4.36 |
| Valid N(listwise) | 43 |  |  |  |  |  |  |

Table 2: Descriptive statistics

However, Ningbo city seems to be a reasonable location for a disaster relief warehouse even take other factors into consideration. Firstly, Ningbo has witnessed continuous and rapid economic development in the Chinese economic reform and has been described by the UN as the most promising city in China. The city now serves as the economic centre for the southern Yangtze River Delta. In other words, the city has a stable society and great infrastructure. Furthermore, Ningbo is in a great logistics condition. The Ningbo Lishe Airport is very large and efficient, can land all aircraft types, and handles about 0.12 million tons of cargo per year. According to the Top 50 World Container Ports announced by World Shipping Council (2017), the port of Ningbo takes the forth place of the list. As Teng (2005) observe that Ningbo port now constitutes a significant threat to Shanghai’s position as the leading container port on the central eastern seaboard of mainland China.

# Discussion and Conclusion

The pre-positioning of disaster relief warehouse is a rather complex problem due to the uncertainty and volatility of the humanitarian supply chain. Unlike general logistics, the main objective for a disaster relief system is fairness and efficiency. In other word, it is all about reducing the response time to a disaster and saving more lives. Thus, minimizing the average distance from the disaster relief warehouse to an affected person takes the priority in making the location selection decision. In this research, the objective was to characterize the pre-positioning problem for humanitarian relief chains in Asia-Pacific region. We attempt to propose an analytical method which will enable relief decision makers to make effective and efficient location and stock pre-positioning decisions for a disaster relief warehouse. A mixed-integer programming (MIP) location model is used to determine the optimal location for the warehouse out of other potential warehouse sites. However, the MIP model is based on the assumption that all the governments are willing to cooperate and support the humanitarian program to operate this warehouse in their country. And the initial capital is supposed to be ample to afford setting the warehouse in any location in Asia-Pacific region. It implies that political factors and cost factors are not significant in this research. There are also some limitations in this research. Firstly, geographical factor is the main factor considered in this study, other factors like political factor or financial factor are not taken into consideration. Secondly, the value of the demand is roughly using the average number of annual affected people instead of specific number of relief material items. Thirdly, the model ignores the connection and cooperation between the potential warehouse and the disaster warehouse that already be established.

Figure 3: Service rate of Ningbo, Dubai and Subang

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